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Test procedures for germanium gamma-ray detectors

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal of establishing a Japanese Industrial Standard from Japan Electric Measuring Instruments Manufacturers' Association (JEMIMA)/Japanese Standards Association (JSA) with a draft of Industrial Standard based on the provision of Article 12 Clause 1 of the Industrial Standardization Law.

This Standard has been made based on **IEC 60973** : 1989 *Test procedures for germanium gamma-ray detectors* for the purposes of making it easier to compare this Standard with International Standard; to prepare Japanese Industrial Standard conforming with International Standard; and to propose a draft of an International Standard which is based on Japanese Industrial Standard.

Attention is drawn to the possibility that some parts of this Standard may conflict with a patent right, application for a patent after opening to the public, utility model right or application for registration of utility model after opening to the public which have technical properties. The relevant Minister and the Japanese Industrial Standards Committee are not responsible for identifying the patent right, application for a patent after opening to the public, utility model right or application for registration of utility model after opening to the public which have the said technical properties.

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Contents

Test procedures for germanium gamma-ray detectors

Introduction This Japanese Industrial Standard has been prepared based on the first edition of **IEC 60973** *Test procedures for germanium gamma-ray detectors* published in 1989.

The portions given dotted underlines are the matters in which the contents of the original International Standard have been modified. A list of modifications with the explanations is given in Annex (informative).

1 Scope This Standard specifies the test procedures for performance and characteristics of the germanium gamma-ray detectors, which are important to manufacturers and users. The test procedures for germanium gamma-ray detectors used for the high-resolution gamma-ray spectroscopy are mainly specified.

NOTE : The International Standard corresponding to this Standard is as follows.

In addition, the symbols which denote the degree of correspondence in the contents between **JIS** and the relevant International Standard are IDT (identical), MOD (modified) and NEQ (not equivalent) according to **ISO/IEC Guide 21**.

IEC 60973 : 1989 *Test procedures for germanium gamma-ray detectors* (MOD)

2 Normative references The following standards contain provisions which, through reference in this text, constitute provisions of this Standard. If the indication of the year of publication is given to these referred standards, only the edition of the indicated year constitutes the provision of this Standard but the revision and amendment made thereafter do not apply. The normative references without the indication of the year of coming into effect apply only to the most recent editions (including amendments).

JIS Z 4001 *Glossary of terms used in nuclear energy*

JIS Z 8103 *Glossary of terms used in measurement*

IEC 60333 : 1993 *Nuclear instrumentation—Semiconductor charged-particle detectors—Test procedures*

IEC 60759 : 1983 *Standard test procedures for semiconductor X-ray energy spectrometers*

3 Terms and definitions For the purposes of this Standard, the definitions given in **JIS Z 4001** and **JIS Z 8103**, and the following definitions apply.

a) **ion implantation** a process in which a beam of energetic ions incident upon the surface of crystal results in the implantation of those ions into crystal

b) **full width at half maximum, FWHM** the full width of a distribution measured at half the maximum value of peak

For a normal distribution, it is equal to 2.35 times the standard deviation σ.

c) **full width at 0.1 maximum, FW0.1M** the full width of a distribution measured at one tenth the maximum value of peak

Also called FW1/10M.

d) **full width at 0.02 maximum, FW0.02M** the full width of a distribution measured at one fiftieth the maximum value of peak

Also called FW1/50M.

e) **high-purity germanium gamma-ray detector, HPGe** a gamma-ray detector which uses a high-purity germanium single crystal (The concentration of impurities is usually 1×10^{10} cm^{-3} or under.)

It should be cooled only at the time of use.

f) **germanium gamma-ray detector** a general term for a high-purity germanium gamma-ray detector, a lithium drift germanium gamma-ray detector, etc.

4 Structure

4.1 General The germanium gamma-ray detector element is a single crystal of germanium which will operate as a diode capable of withstanding high reverse bias voltage at cryogenic temperature (liquid nitrogen temperature range). When the reverse bias voltage is applied, the depletion region is formed in the bulk of the detector. Under these conditions, electrons and electron holes generated by the interaction of photons are swept to respective electrodes in the depletion region. The induced charge is integrated to produce an output pulse whose magnitude is proportional to the absorbed photon energy.

The germanium gamma-ray detector is usually mounted in a cryostat to permit cooling the detector and maintaining it at cryogenic temperature for the purpose of reducing leakage current and thermal noise. The cryostat also provides protection and appropriate environment for the detector.

For the usual germanium gamma-ray detector, a germanium crystal, a preamplifier, a high voltage filter and a cryostat are combined in an integrated unit, and it is not practical to measure performance of the detector as a single unit which is isolated from the preamplifier.

4.2 Detector classification Germanium gamma-ray detector types are classified by material and geometry.

a) **Classification by material** Materials used are p-type germanium and n-type germanium. A high-purity germanium gamma-ray detector which uses a high-purity germanium single crystal is usually used.

   1) **p-type detector** The p-type detector is made with p-type germanium crystal [see figure 2 a)] with an n^+ outer electrode (usually lithium diffusion with a dead-layer of 0.5 mm to 0.8 mm in thickness). The p^+ inner electrode is made by ion implantation of boron and the like. High positive voltage is applied to the n^+ outer electrode to form depletion region.

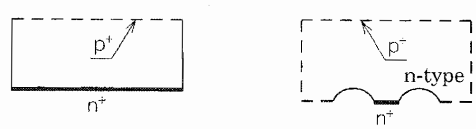
2) **n-type detector** The n-type detector which is also called the reverse-electrode detector is made with n-type germanium crystal with a p^+ outer electrode. This outer electrode is made by ion implantation of boron and the like [see figure 2 b)]. The inner electrode is usually made by lithium diffusion. High negative voltage is applied to the p^+ outer electrode to form depletion region. Thin (approximately 0.3 μm) outer electrode makes it possible to use this detector also for low energy X-ray detector. The n-type detector is more resistant to neutron damage than the p-type detector.

b) **Classification by geometry** Geometries usually used are a planar type and a coaxial type. The difference depends on the structure of electrodes. The planar type is usually a disc shape with electrodes of parallel planes (see figure 1). The coaxial type has electrodes of the coaxial cylinder shape of which one end is closed (see figure 2).

1) **Planar type detector** The planar type geometry is useful for constructing small-diameter detectors and/or low capacitance detectors which make possible low noise, and has characteristics for obtaining high resolution especially for low energy X-rays. Some planar type detectors also have large front surface areas with high capacitance, and are capable of detecting even low-energy X-rays by making the outer electrode thin. Planar type detectors include the general type and the hybrid type. The general type is a simple flat-plates in parallel structure [see figure 1 a)]. The hybrid type structure is such that the one side electrode area is made small to achieve low capacitance [see figure 1 b)].

2) **Coaxial type detector** The coaxial type geometry makes possible detectors with high capacitance to be able to obtain relatively high efficiency for detecting high energy gamma-rays.

3) **Well-type coaxial detector** The well-type coaxial detector has a structure in such a way that the sample can be inserted in the inner electrode. The sample is essentially surrounded by the detector [see figure 2 c)].

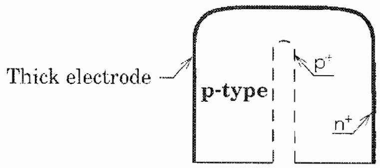


a) General type detector (p-type or n-type)

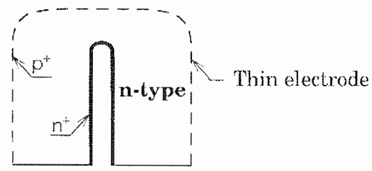
b) Hybrid type detector

NOTE : The dotted line indicates a thin p^+ electrode, and the thick solid line indicates a relatively thick n^+ electrode.

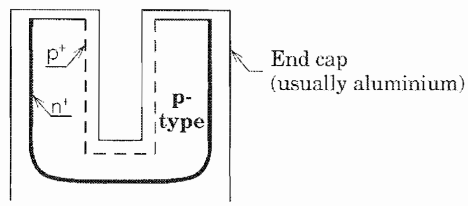
Figure 1 Planar type detector



a) **Coaxial type detector (p-type)**



b) **Coaxial type detector (n-type)**



c) **Well-type coaxial detector**

NOTE : The dotted line indicates a thin p^+ electrode, and the thick solid line indicates a relatively thick n^+ electrode.

Figure 2 Coaxial type detector

5 General test conditions Although it is not necessary to perform all tests specified in this Standard, when tests concerned are performed, the procedures specified in this Standard shall be followed except when agreed between the parties concerned with delivery.

The general test conditions specified in this Standard shall be as follows.

a) The maximum apply voltage, device ambient temperature and environment and other operational conditions specified by manufacturers should not exceed limits when testing since permanent changes of the detector performance may result.

b) The high voltage power supply, amplifier, multichannel pulse-height analyzer, and other equipment used for the test shall not significantly influence the performance test for the detector because of their instability, nonlinearity or other performances.

c) Changes in measurement system components or changes in system parameters (e.g. amplifier gain) shall not be made without complete system recalibration.

d) The performance test results should be reproducible within the measurement precision range after any one or all tests are completed.

6 Energy spectroscopy measurement For the energy spectroscopy measurement, unless specially agreed between the parties concerned with delivery, a spectral peak shall be at least six channels at FWHM and the total counts within FWHM shall be at least 50 000. The radiation source shall be located on-axis of the detector and 25.0 cm from the end cap surface.

6.1 Recommended radiation source Radiation sources given in table 1 are recommended as radionuclide sources for the measurement of energy resolution of the detector and/or the spectroscopy system.

Table 1 Recommended radiation source

Radionuclide source	Half-life	Energy
^{55}Fe	2.7 years	5.9 keV
^{241}Am	433 years	59.5 keV, 26.36 keV. X-rays
^{109}Cd	453 days	22.1 keV (X-ray, doublet peak), 88.0 keV
^{57}Co	270 days	122.1 keV, 136.5 keV
^{137}Cs	30 years	661.6 keV
^{22}Na	2.60 years	1 274.5 keV
^{60}Co	5.24 years	1 173.2 keV, 1 332.5 keV([1])
^{208}Tl (nuclide series of ^{228}Th)	1.91 years	2 614.5 keV

Note ([1]) 1 332.5 keV of ^{60}Co is the gamma-ray preferred for the performance test of a coaxial detector.

For the multi-line gamma-ray sources, ^{56}Co (half-life 77 days) with energy range from 847 keV to 3 600 keV, and ^{152}Eu (half-life 13 years) with energy range from 122 keV to 1 769 keV may be used. In the energy resolution measurement, it is assumed that the measurement system is energy calibrated in units of eV, or keV per channel.

The energy calibration shall be performed by using plural gamma-rays which should be sufficiently close in energy to the peak under study to reduce problems arising from measurement system nonlinearities. For example, in the case of ^{60}Co, 1 173.2 keV and 1 332.5 keV gamma-rays are suitable for this purpose. In the case of the mono-energetic gamma-ray emitter ^{137}Cs, ^{207}Bi (569.7 keV) or ^{54}Mn (835 keV) should be combined.

6.2 Connection method of test equipment Connect the preamplifier, main amplifier, and multichannel pulse-height analyzer to the detector as shown in figure 3.

The detector and preamplifier are usually supplied as an integral unit. The main amplifier shaping is usually set to the conditions to obtain the optimum performance of the detector. The method and parameters of main amplifier shaping used shall be given with each energy resolution measurement results or specifications. A pulse generator (see **IEC 60333**) connected to the measurement system can be run simultaneously with the gamma-ray measurement, provided that it does not distort other peaks (e.g. by baseline undershoot) or cause significant errors in dead-time correction for the detection efficiency measurement.

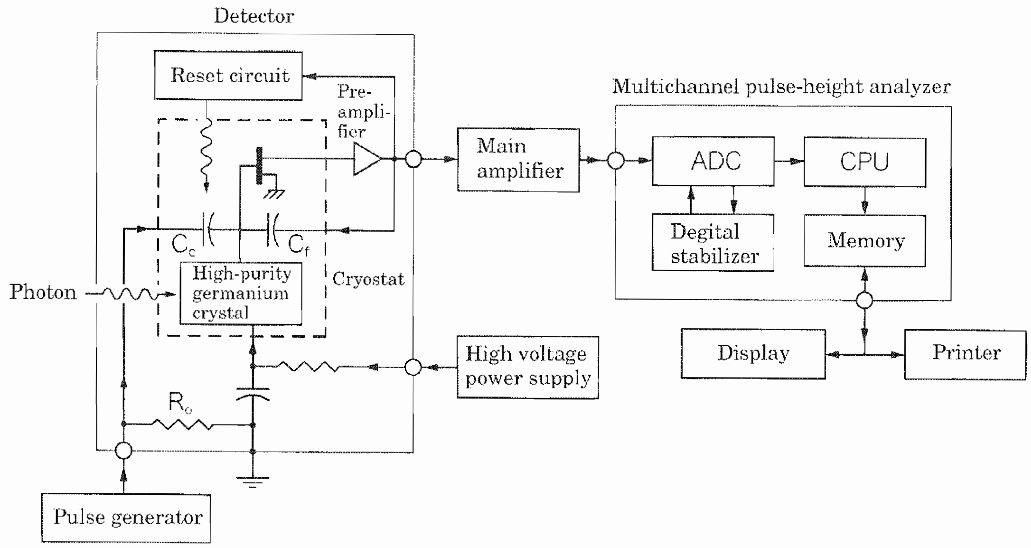


Figure 3 Block diagram of typical germanium gamma-ray spectroscopy system

6.3 Determination of peak area Although the method of peak area determination (net counts of peak) includes many methods such as a method of summing the counts per channel and a peak function fitting method, a peak-sum method shall be specified in this Standard so that the calculation result of peak area can be easily ensured. Even in the peak-sum method, although there are some methods for determination of a baseline area, here, the following two methods shall be specified. Either method may be used, however, the method by which the test is performed shall be clearly stated.

Information : For the method **a**), in the case of a high-resolution germanium gamma-ray detector, accuracy becomes poor according to how to draw a straight baseline. Furthermore, since the method **a**) is complicated because it requires the determination of baseline counts per channel and so on, the method **b**) is usually used.

a) For the method of calculating baseline area by summing baseline counts per channel, the procedure shall be as follows.

1) As shown in figure 4, pulse-height distribution shall be plotted as the log of the number of counts N_X in channel X versus channel number X. On this semilog plot, the straight line a–d shall be fitted to represent an approximation of the baseline under the peak. The mean value of 10 data points above and below the peak may be used to fit the baseline.

2) Draw a smooth curve through the peak data points, extending the curve on each side at the base of the peak to intersect the baseline (curve A–B and curve C–D).

3) The area below the straight line (A–D) bounded by two points of intersection with the peak curve shall be taken as the baseline area.

4) The total peak area A_t shall be obtained by summing the counts per channel between two points of intersection with the straight baseline.

$$A_t = \sum_{X=A}^{D} N_X \qquad (1)$$

where, N_X : number of counts in channel X

5) Similarly, the baseline area A_b shall be obtained by summing baseline counts B_X per channel in channel X.

$$A_b = \sum_{X=A}^{D} B_X \qquad (2)$$

6) The peak area A shall be as the formula (3).

$$A = A_t - A_b \qquad (3)$$

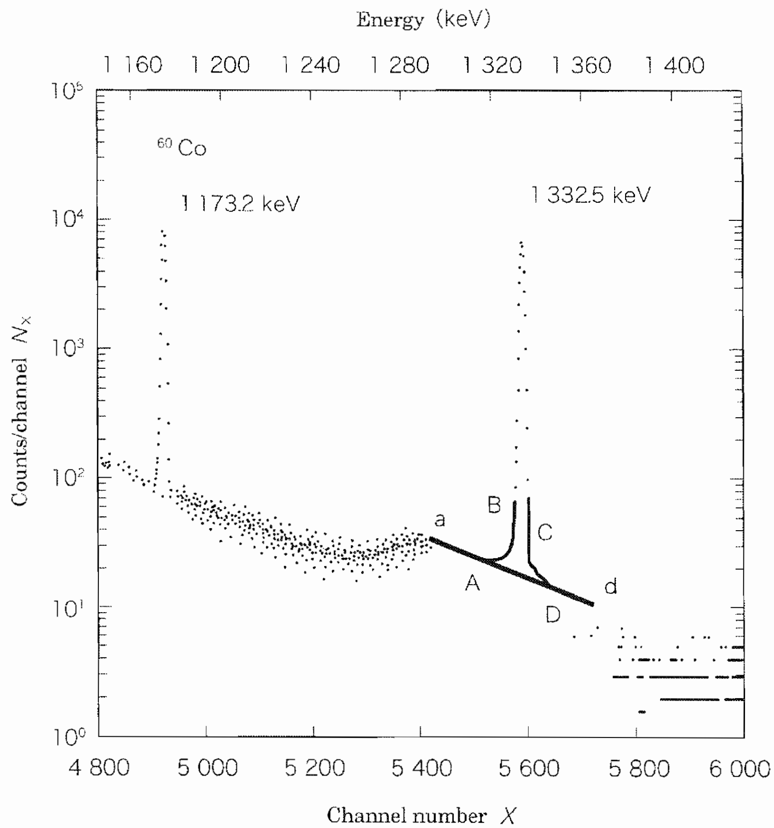


Figure 4 Method of calculating baseline area by summing baseline counts per channel

b) For the method using trapezoidal approximations for baseline area, the procedure shall be as follows.

1) As shown in figure 5, regard the baseline below the peak as a straight line.

2) Set the peak region (L to H) wider by some channels from both ends of the peak.

3) Obtain the total peak area A_t by summing counts in each channel.

$$A_t = \sum_{X=L}^{H} N_X \quad \cdots\cdots (4)$$

where, N_X : number of counts in channel X

4) The baseline area A_b in the peak domain shall be as the formula (5).

$$A_b = \frac{1}{2}(H - L + 1)(N_L + N_H) \quad \cdots\cdots (5)$$

where, N_L : number of counts in channel number L

N_H : number of counts in channel number H

For N_L and N_H, the mean value of some left and right points ($L \pm k$, $H \pm k$, $k = 1$ to 5) may be used to make statistical fluctuation small. However, when the centre of the peak is taken as $\hat{X}$, $L_2 + k \leqq \hat{X} - 1.5\text{FWHM}$ and $H_2 - k \geqq \hat{X} + 1.5\text{FWHM}$ shall be followed.

5) The peak area A shall be as the formula (3).

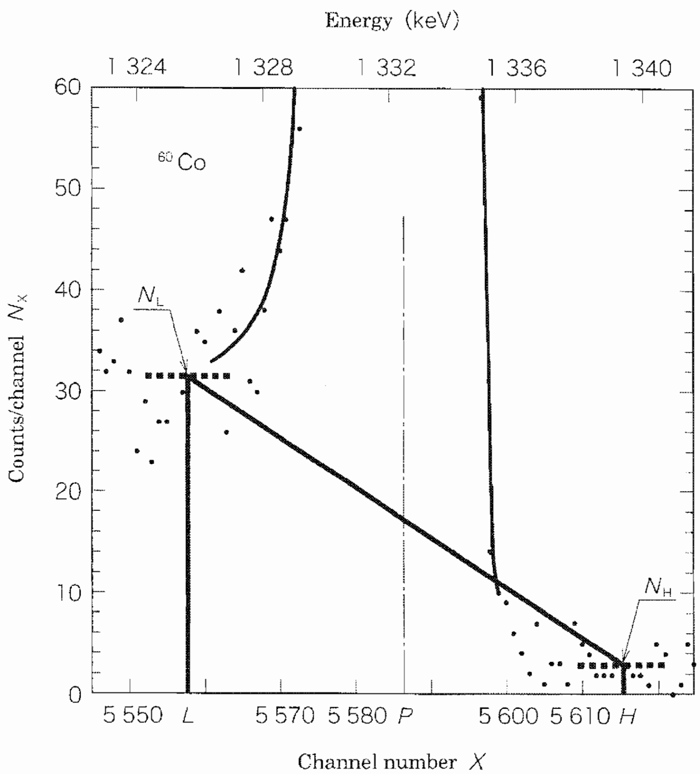


Figure 5 Method to approximate baseline area using trapezoidal area

6.4 Determination of peak channel For each channel, calculate the number of counts per channel from which the baseline counts are reduced ($N_X - B_X$). Determine the channel $\hat{X}$ corresponding to the maximum monoenergetic spectral peak by interpolation. For example, the method to determine the weighted average of the symmetrical portions of the peak above the half number of peak counts by using the formula (6) is convenient.

$$\hat{X} = \sum X(N_X - B_X) / \sum (N_X - B_X) \quad \cdots\cdots (6)$$

6.5 Determination of FWHM, FW0.1M and FW0.02M of peak Determine 1/2, 1/10 and 1/50 of the maximum of peak by a linear plot of $N_X - B_X$ versus X. Determine FWHM, FW0.1M and FW0.02M of the peak in channels ΔN_s by interpolation (see figure 6). These ratios (FW0.1M/FWHM and FW0.02M/FWHM) are often given as indicators of peak shape quality.

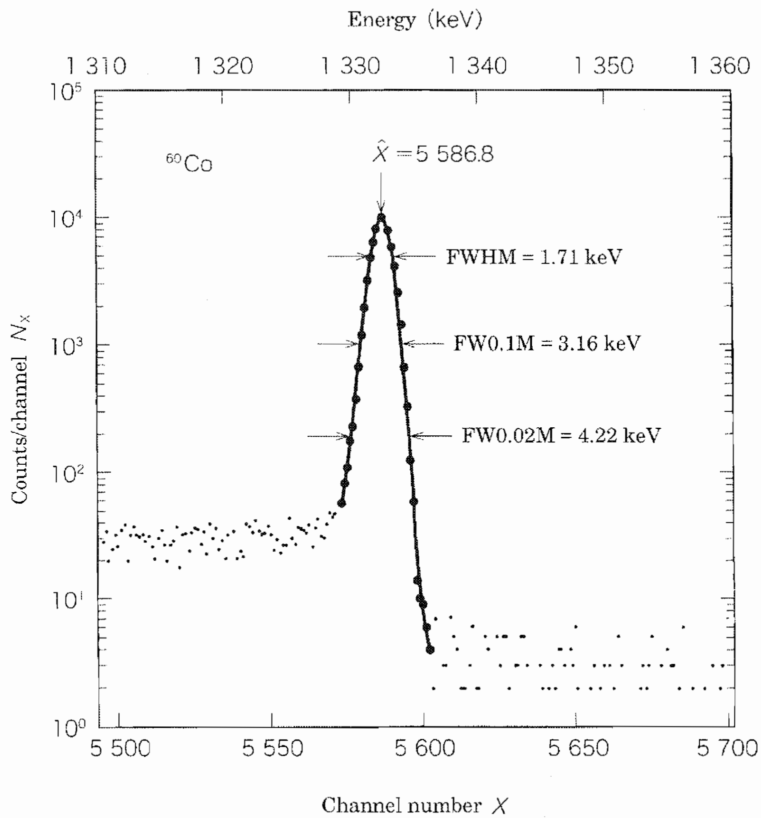


Figure 6 FWHM, FW0.1M, FW0.02M of peak of 1 332.5 keV gamma-ray (^{60}Co)

6.6 Determination of peak-to-Compton ratio Determine the average number of counts $\overline{N_c}$ of the Compton continuum portion defined by relatively flat interval from 1 040 keV to 1 096 keV for 1 332.5 keV gamma-ray of ^{60}Co. These regions shall avoid the Compton edge. The peak-to-Compton ratio is defined as the ratio of the maximum number of counts in the peak N_X at channel $\hat{X}$ to $\overline{N_c}$ (see figure 7).

The peak-to-Compton ratio is one of the detector performance index which depends on the geometry of the detector, the mount method and cryostat structure, the counting efficiency and the energy resolution. The peak-to-Compton ratio is inversely proportional to the energy resolution if other factors remain unchanged. It usually increases with increasing counting efficiency, however, the extent of this effect is limited depending on the detector geometry.

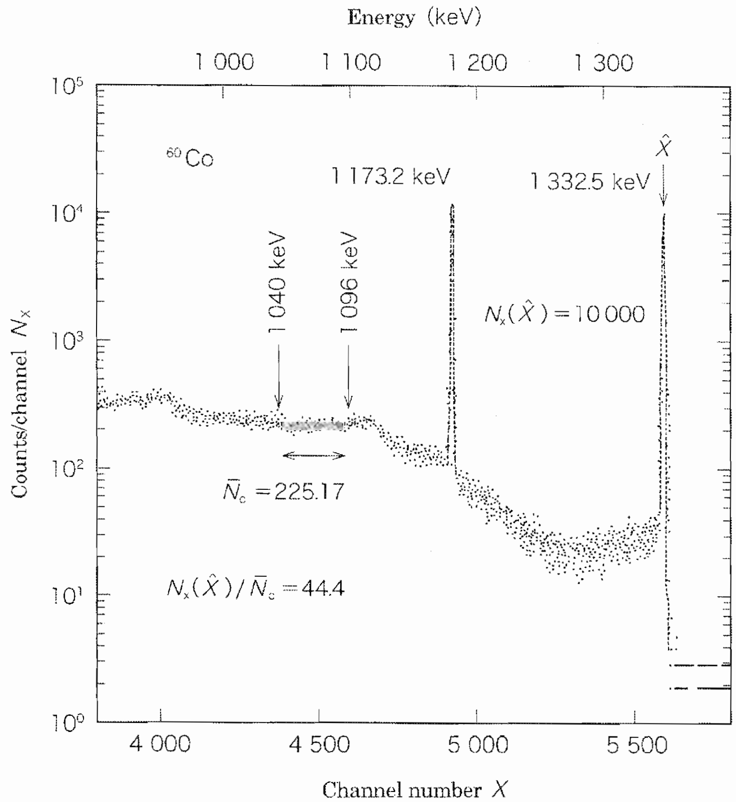


Figure 7 Determination of peak-to-Compton ratio (P/C) for 1 332.5 keV gamma-ray (^{60}Co)

6.7 Determination of energy resolution The gamma-ray peak to be measured and a second gamma-ray peak should be located in the same spectrum and their centres $\hat{X}_1$ and $\hat{X}_2$ should be determined for the purpose of energy calibration (see **6.4**). The second peak may be produced by a calibrated pulse generator (see **4.1** of **IEC 60333**, for calibration of pulse generator).

On a plot of $N_X - B_X$, determine FWHM of the peak in channels ΔN_S by interpolation. The energy resolution ΔE_S expressed in energy units shall be as the formula (7).

$$\Delta E_S = \frac{E_1 - E_2}{\hat{X}_1 - \hat{X}_2} \Delta N_S \quad \cdots\cdots (7)$$

where, E_1 : energy of peak to be measured

$\hat{X}_1$: centre channel of peak to be measured

E_2 : energy of second peak

$\hat{X}_2$: centre channel of second peak

The type of amplifier shaping used and the conditions thereof (e.g. shaping time) shall be clearly stated when describing the energy resolution measurement or specification.

When the energy resolution is measured specially at a high count rate, the count rate and the performance of the preamplifier used (maximum count rate-energy product, hereafter referred to as "CREP") also shall be clearly stated. The CREP corresponds to the maximum energy input at which the preamplifier will still operate within its linear response range. For example, in a resistive feedback preamplifier, the maximum CREP is determined by the feedback resistor and the maximum feedback voltage. The CREP is defined as the formula (8).

$$\mathrm{CREP} = \sum_{E} E \times r_E \ (\mathrm{keV} \times \mathrm{s}^{-1}) \quad \cdots\cdots (8)$$

where, r_E : count rate (s^{-1}) at energy E (keV)

6.8 Determination of total noise linewidth and detector contribution Obtain ΔE_s, FWHM for the gamma-ray peak, and ΔE_r, FWHM for the pulse generator peak, by measuring a peak of the gamma-ray spectrum and a peak of the pulse generator. Refer to **IEC 60333** if more information about the usage of pulse generator for the noise measurement is needed. ΔE_r is the total noise linewidth for the spectroscopy measurement system. The contribution to FWHM for the gamma-ray peak due to all factors other than electrical noise ΔE_0 shall be as the formula (9).

$$\Delta E_0 = (\Delta E_s^2 - \Delta E_r^2)^{\frac{1}{2}} \quad \cdots\cdots (9)$$

If the data have been acquired at a sufficiently low count rate to eliminate characteristics of count rate effects, ΔE_0 is primarily due to the detector charge generation and collection processes and is an important characteristic of the detector.

6.9 Determination of peak asymmetry The measurement should be made at low count rate of 1 000 s^{-1} or under to make count rate effects to the peak asymmetry negligible. The determination of peak asymmetry shall be as follows.

On a semilog plot of $(N_X - B_X)$ versus X-axis, draw a line from the apex of peak channel $\hat{X}$ perpendicular to X-axis. At 1/10 height of the peak, measure the interval L, from the low energy side point to the midline, (see figure 8). Measure the corresponding interval H on the high energy side (see figure 8). Quote peak asymmetry as the ratio H/L and also show the gamma-ray energy for which it applies.

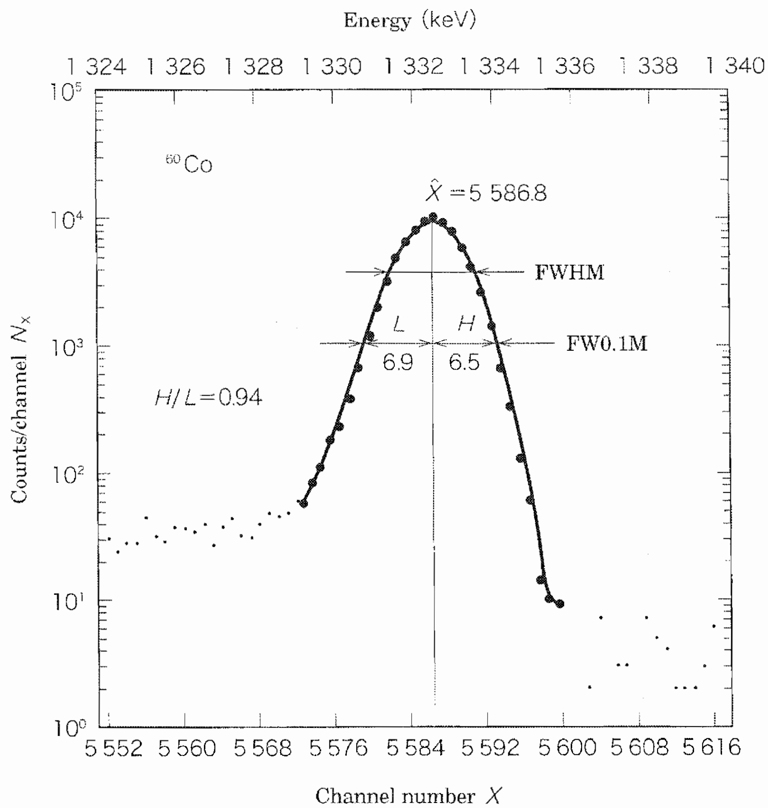


Figure 8 Determination of peak asymmetry as ratio *H*/*L*

6.10 Determination of energy resolution of well-type coaxial detector The energy resolution measurement for well-type coaxial detectors shall be made so that the point source is located on-axis approximately 1.0 cm from the bottom centre of the well [see figure 2 c)]. Detectors with a low electric field strength near the electrode will perform poorly with the source inside the well due to poor charge collection near the electrode. The measurement method and radionuclide sources used are otherwise the same as for other germanium gamma-ray detectors.

6.11 Preferred energy When the energy resolution is tested, it is preferred to make measurements at specific energies chosen according to the energy range for which the detector is to be evaluated. The preferred energy and radionuclide according to energy range shall be as given in table 2.

Table 2 Preferred energy

Energy range	Preferred energy and radionuclide
1 MeV or over	1 332.5 keV (^{60}Co)
400 keV or over to and excl. 1 MeV	661.6 keV (^{137}Cs)
70 keV or over to and excl. 400 keV	122.1 keV (^{57}Co)
Under 70 keV	5.9 keV (^{55}Fe), 22.1 keV (^{109}Cd), 59.5 keV (^{241}Am)

NOTE : See **6.1** for a wider range of energy.

7 Determination of counting efficiency The counting efficiency for a full energy peak depends on the active volume and shape of the germanium gamma-ray detector, the allocation of radionuclide source to the detector and the structure of the vicinity of detector. The counting efficiency is defined as that of the complete detector assembly including not only the detector but the vicinity structure.

In this Standard, the following two allocations of radionuclide source to the detector shall be specified.

a) a point source 25.0 cm from the centre of the detector endcap surface

b) a point source on-axis 1.0 cm from the bottom centre of the well of a well-type coaxial detector

While representative, these allocations do not correspond to all of the possible geometries. However, measurements under these conditions will provide a reference for performance testing, comparing and selecting of detectors.

When the counting efficiency is used to show the performance, the measurement method shall be clearly stated.

Although the counting efficiency may be obtained using the volume source which simulates an actual measurement sample, in this case, specifications such as the shape of the simulated volume source shall be clearly stated.

7.1 Efficiency for a point source at 25.0 cm

7.1.1 Determination of absolute full-energy peak counting efficiency With the detector connected to the auxiliary electronic equipment as shown in figure 3, a spectrum using a calibrated ^{60}Co radionuclide source shall be measured. The distance from the centre of the radionuclide source to the centre of the endcap surface shall be 25.0 cm. The absolute full-energy peak counting efficiency E_a shall be the ratio of the number of counts A in the full-energy peak to the number of 1 332.5 keV gamma-ray N_s emitted by the radionuclide source during the counting time (live time).

$$E_a = A / N_s \quad \cdots\cdots (10)$$

Alternatively, the counting time may be determined from the area of a pulse peak run at a constant known rate with the pulse generator appearing approximately 5 % above the gamma-ray peak in energy. For the counting efficiency measurement in which a radionuclide source is close to the endcap, this method is useful.

7.1.2 Determination of relative full-energy peak counting efficiency The efficiency E_{rel} of a germanium gamma-ray detector relative to the counting efficiency of a 3 inch × 3 inch (76 mm × 76 mm) NaI (Tl) scintillation detector at a radionuclide source-to-detector distance of 25.0 cm (as defined in **7.1.1**) shall be as the formula (11).

$$E_{rel} = E_a / E_{NaI} \quad \cdots\cdots (11)$$

where, E_a : total energy counting efficiency according to formula (10)

E_{NaI} : total energy counting efficiency of 3 inch × 3 inch (76 mm × 76 mm) NaI (Tl) scintillation detector

The value of E_{NaI} corresponding to 1 332.5 keV gamma-ray emitted by ^{60}Co shall be 1.20×10^{-3} when the radionuclide source to detector endcap centre distance is 25.0 cm.

7.2 Determination of gamma-ray counting efficiency of well-type coaxial detector For the determination of gamma-ray counting efficiency of well-type coaxial detector, although the method specified in **7.1** is usually used, there is also a measurement method by inserting a radionuclide source in the well. Although either method may be used, when the counting efficiency is used to show the performance, the measurement method shall be clearly stated.

For the measurement method by inserting a radionuclide source in the well, a radionuclide source is surrounded by the germanium crystal [figure 2 c)] and this results in a high counting efficiency for the gamma-ray. Furthermore, thus, the fraction of coincident gamma-rays which are summed becomes much greater than the case when the radionuclide source is located outside the endcap, and these coincident gamma-rays shall appear in the spectrum as the apparent sum peak. The sum peak represents the occurrence of the coincident full-energy absorption of two gamma-rays.

The measurement method by inserting a radionuclide source in the well shall be as follows.

a) For one of two coincident gamma-rays, the number of gamma-ray detected at full energy is equal to the sum of the counts in the full energy peak A and the counts in the sum peak A_s. For an accurate measurement, the number of gamma-ray detected for coincident gamma-rays shall be represented by $A + A_s$.

b) The true effect of coincident summing in a well-type coaxial detector is especially important for specifying the counting efficiency performance of the detector. As the absolute efficiency of the detector goes up, the fraction of count fall of the full energy peak A by the sum peak becomes greater, and the ratio A_s/A increases. Thus, if only the counts in the full energy peak A is used to calculate the absolute efficiency, the calculated efficiency will become progressively deficient as the actual efficiency increases. When calculating the counting efficiency of the detector using one of two coincident gamma-rays, $A + A_s$ shall be used for the counts at full energy corresponding to that gamma-ray.

c) The counting efficiency of well-type coaxial detector (2) should be measured so that the point source of ^{60}Co of less than 2.0 mm in dimension is approximately 1.0 cm above the bottom of the endcap well by the method specified in **6.2**. The counting of accidental coincidences shall be made negligible or collectable by the count rate and amplifier shaping time control and/or through the use of pulse-pile-up rejection. The 1 332.5 keV gamma-ray of ^{60}Co is in coincidence with the 1 173.2 keV gamma-ray resulting in a sum peak at 2 505.7 keV.

Note (2) The active volume (cm^3) of germanium crystal is one of the indicator to show the counting efficiency of well-type coaxial detector, however, the user has no way to verify the active volume. Also, it is not a reliable indicator for the counting efficiency, therefore, the active volume (cm^3) of germanium crystal is not acceptable for the performance indication of the detector.

d) The peak area of 1 332.5 keV and 2 505.7 keV of ^{60}Co should be determined according to the method of **6.3**. The counting efficiency (W) of the well-type coaxial detector shall be as the formula (12).

$$W = \frac{A + A_s}{N_s} \quad \cdots\cdots (12)$$

where, A : peak area of 1 332.5 keV peak

A_s : peak area of 2 505.7 keV sum peak

N_s : number of 1 332.5 keV gamma-ray emitted by nuclide source during live time

8 Window thickness index The window thickness (detector dead-layer, cryostat, endcap, etc.) shall be evaluated by measuring the three peak areas for 31.0 keV, 35.0 keV and 79.6 keV/81.1 keV emitted by ^{133}Ba and by reporting these ratios as a window thickness index. The ratio of peak area for 22 keV and 88 keV of ^{109}Cd or 43 keV and 86.5 keV of ^{155}Eu may also be used. For both cases, ensure that the self-absorption in radionuclide source and absorption of housing are negligible.

A window thickness index based on the X-ray fluorescence is used for the thin window thickness. Such an index is specified in **IEC 60759** and the thickness index is based on the X-ray fluorescence of standard glass.

This glass contains oxides of Si, Ba, Ca, Li, Mg, Zn and B. When the X-ray fluorescence is generated by a ^{55}Fe radionuclide source, it emits numerous X-rays in the region from 1 keV to 5 keV. Ratios of these X-rays to the coherently backscattered 5.9 keV X-ray from the radionuclide source shall be used for the window thickness index.

9 Timing A useful method for measuring the timing capability of the germanium gamma-ray detector is based on a coincident measurement detecting two 511 keV annihilation radiation emitted by ^{22}Na in opposite directions. In addition to this, there is also a coincident measurement method of gamma-rays emitted in cascade by ^{60}Co. A start signal from the germanium gamma-ray detector under test and a delayed stop signal obtained from other high-speed detector are required. The distribution of the time difference between the start signal and the stop signal shall be measured by a time-to-amplitude converter (TAC) and the timing resolution of the system shall be obtained. If the high-speed detector and the electronic circuit of the system are faster, information on the timing resolution of that germanium gamma-ray detector can be obtained. However, the timing measurement depends on the entire system and its adjustment, the result of timing measurement should not be considered solely as the characteristics of the detector.

9.1 Measurement system of timing resolution A typical system for measuring the timing resolution of germanium gamma-ray detector is shown in figure 9. The stop signal is the signal from a high-speed plastic scintillator mounted on a relatively fast photomultiplier (total rising time shall be 5 ns or under). The signal from the photomultiplier is sent to a constant-fraction timing discriminator (hereafter referred to as "CFTD"), delayed a few nanoseconds by the delay circuit and input to the stop side of a time-to-amplitude converter (TAC). Several calibrated delay circuits are required for the calibration of the time axis.

The signal from the germanium gamma-ray detector shall be split in two at the output of the preamplifier.

For one, the signal from the preamplifier is sent to a fast shaping amplifier with a differentiation time constant approximately equal to the fastest rising time observable at the preamplifier output. The output signal is then sent to a CFTD. The fraction of the pulse-height level at the CFTD should be 20 % and the shaping delay should be one and a half times the rising time which is the fastest signal observed at the output of the preamplifier. This parameter combination helps to minimize the timing uncertainties due to rising time and pulse-height variations.

For the other, the signal is sent to an amplifier and a single-channel analyzer (SCA), which is used as the gate signal of the multichannel analyzer. The positron annihilation radiation by ^{22}Na radionuclide source should be centered on 511 keV with 10 % window width by SCA.

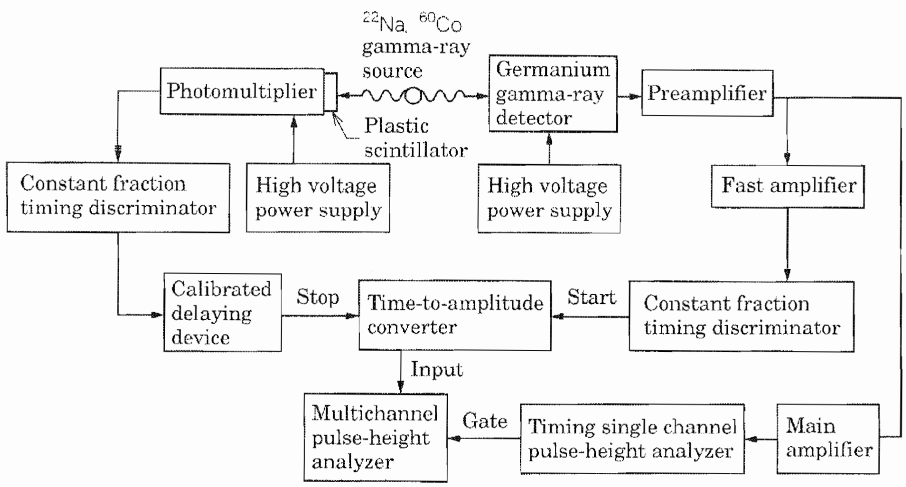


Figure 9 Measuring system of timing and time spectrum

9.2 Determination of timing resolution An example of the measuring system in which the time spectrum of the gamma-ray coincidence count is obtained is shown in figure 9. Also, a typical spectrum is shown in figure 10. The number of channels between FWHM shall be at least six, and the total number of counts within FWHM shall be at least 4 000. After calibrating the time axis using at least two calibrated delay time, FWHM and FW0.1M shall be determined in units of nanoseconds. The following parameters shall be recorded to ensure the reproducibility of the timing resolution test.

a) Apply voltage to germanium gamma-ray detector and scintillator detector

b) Shaping conditions of plastic scintillator system fast shaping amplifier and germanium gamma-ray detector system amplifier

c) Delay time of stop signal

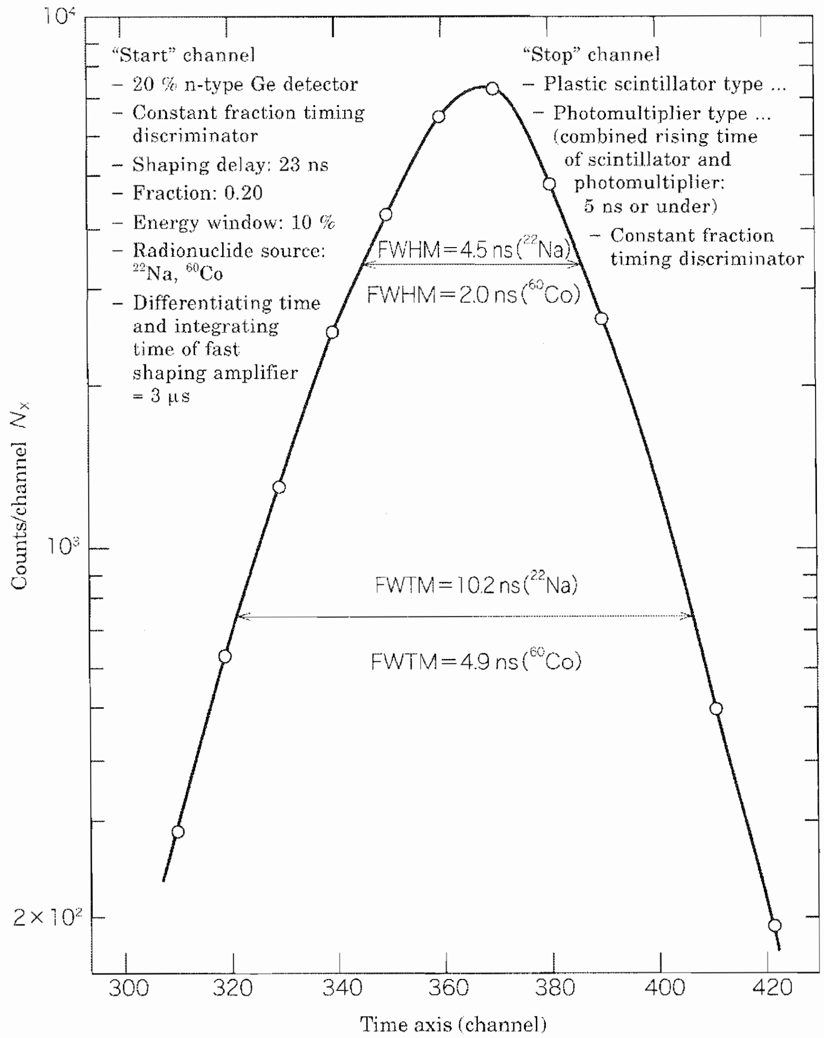


Figure 10 Timing resolution of germanium gamma-ray detector (example)

10 Temperature cycle

10.1 Temperature cyclable detector The temperature cyclable detector (generally high-purity germanium gamma-ray detector) shall be especially useful for such as a portable detector and the case where a continuous supply of liquid nitrogen is not ensured. A cyclable detector shall also remain under vacuum if it is integrated with the cryostat. For the temperature cyclable detector, manufacturers shall guarantee that the detector shall maintain its performance throughout the warranty period under conditions of unlimited cycling between room temperature and liquid nitrogen temperature and of indefinite room temperature storage.

10.2 Annealable detector The annealable detector shall be designed so that they do not degrade when subjected to a specified temperature for a given time to repair the damage due to radiation (specially fast neutron) (see **10.1**). The cryostat, detector

and mount method shall be capable of accommodating the annealing (such as 120 °C for 24 h). It should be such that in the absence of radiation damage, the detector will be able to tolerate this annealing without degrading its performance beyond specified limits.

Proper annealing can restore the radiation-damaged high-purity germanium gamma-ray detector to its approximate condition prior to damage. Compared to the p-type coaxial detector, the n-type coaxial detector is less sensitive to radiation damage and also the efficiency degrading by annealing is small.

Annex (informative)
Comparison table between JIS and corresponding International Standard

JIS Z 4520:2007 *Test procedures for germanium gamma-ray detectors*					**IEC 60973**:1989 *Test procedures for germanium gamma-ray detectors*		
(I) Requirements in **JIS**		(II) International Standard number	(III) Requirements in International Standard		(IV) Classification and details of technical deviation between **JIS** and the International Standard by clause Location of deviation: text Indication method: dotted underlines		(V) Justification for the technical deviation and future measures
Clause	Content		Clause	Content	Classification by clause	Detail of technical deviation	
1 Scope	The test procedures for germanium gamma-ray detectors are specified.	**IEC 60973**	1 2	Identical with **JIS**.	IDT	—	—
2 Normative references	**IEC 60333** **IEC 60759**		—	Identical with **JIS**.	IDT	In **IEC** Standard, although there is not clause of normative references, PREFACE includes explanation of normative references.	—
	JIS Z 4001 **JIS Z 8103**			—	MOD/ addition	Standards of glossary of terms are added.	In **IEC** Standard, definitions of terms are specified in the text. In **JIS**, normative references are specified.
3 Terms and definitions	The definitions given in **JIS Z 4001** and **JIS Z 8103** and the definitions of six terms are specified.		3	Symbols and definitions	MOD/ deletion	In **IEC** Standard, although symbols and terms are defined, some are not used in the text. In **JIS**, symbols and terms not used are deleted.	No difference in technical content.

(I) Requirements in **JIS**		(II) International Standard number	(III) Requirements in International Standard		(IV) Classification and details of technical deviation between **JIS** and the International Standard by clause Location of deviation: text Indication method: dotted underlines		(V) Justification for the technical deviation and future measures
Clause	Content		Clause	Content	Classification by clause	Detail of technical deviation	
4 Structure 4.1 General 4.2 Detector classification	 Structure of germanium gamma-ray detector Detector types		4 4.1 4.2 4.3	Introduction The interaction of gamma-rays with matter The germanium gamma-ray detector Germanium detector types Almost identical with **JIS**.	 MOD/ deletion MOD/ deletion MOD/ alteration	Clause 4 in **IEC** Standard describes the content which is not completely related to the test method. In **JIS**, **4.1** and **4.2** are deleted. Only **4.3** which is modified is specified.	The technical content is not basically modified.
5 General test conditions			5	Identical with **JIS**.	IDT	—	—
6 Energy spectroscopy measurement			6	Identical with **JIS**.	IDT	—	—
6.1 Recommended radiation source			6.1	Identical with **JIS**.	IDT	—	—
6.2 Connection method of test equipment			6.2	Identical with **JIS**.	IDT	—	—
6.3 Determination of peak area			6.3	Almost identical with **JIS**.	MOD/ selection	In **JIS**, the method different from the method in **IEC** Standard is added, and it is specified that either method may be used.	Because in the current system, the test method added in **JIS** is generally used. The proposal of revision will be presented when **IEC** Standard is reviewed.

(I) Requirements in **JIS**		(II) International Standard number	(III) Requirements in International Standard		(IV) Classification and details of technical deviation between **JIS** and the International Standard by clause Location of deviation: text Indication method: dotted underlines		(V) Justification for the technical deviation and future measures
Clause	Content		Clause	Content	Classification by clause	Detail of technical deviation	
6.4 Determination of peak channel			6.4	Identical with **JIS**.	IDT	—	—
6.5 Determination of FWHM, FW0.1M and FW0.02M of peak			6.5	Identical with **JIS**.	IDT	—	—
6.6 Determination of peak-to-Compton ratio			6.6	Identical with **JIS**.	IDT	—	—
6.7 Determination of energy resolution			6.7	Identical with **JIS**.	IDT	—	—
6.8 Determination of total noise linewidth and detector contribution			6.8	Identical with **JIS**.	IDT	—	—
6.9 Determination of peak asymmetry			6.9	Almost identical with **JIS**.	MOD/addition	In **JIS**, "1 000 s^{-1} or under" is added as the numerical value of count rate.	Because specificity is given to the test method.
6.10 Determination of energy resolution of well-type coaxial detector			6.10	Identical with **JIS**.	IDT	—	—

(I) Requirements in **JIS**		(II) International Standard number	(III) Requirements in International Standard		(IV) Classification and details of technical deviation between **JIS** and the International Standard by clause Location of deviation: text Indication method: dotted underlines		(V) Justification for the technical deviation and future measures
Clause	Content		Clause	Content	Classification by clause	Detail of technical deviation	
6.11 Preferred energy			6.11	Almost identical with **JIS**.	MOD/ addition	In **JIS**, 59.5 keV (^{241}Am) is added to the recommended energy value.	Because it is generally used.
7 Determination of counting efficiency			7	Almost identical with **JIS**.	MOD/ deletion	The standard Marinelli beaker described in **IEC** Standard is deleted.	Because there is not the standard Marinelli beaker in Japan. The proposal of revision will be presented when **IEC** Standard is reviewed.
					MOD/ addition	The sentence which allows the specification of volume source is added.	Because the test method added in **JIS** is generally used. Furthermore, there is no substantial difference in the test method.
7.1 Efficiency for a point source at 25.0 cm			7.1	Identical with **JIS**.	IDT	—	—
7.2 Determination of gamma-ray counting efficiency of well-type coaxial detector			7.2	Almost identical with **JIS**.	MOD/ selection	In **JIS**, the method which is different from the method in **IEC** Standard (the method specified in **7.1**) is added, and it is specified that either method may be used.	Because the test method which is added in **JIS** is generally used.
—	—		7.3	Counting efficiency of gamma-ray when using a standard Marinelli beaker.	MOD/ deletion	—	See (V) of column 7.

(I) Requirements in **JIS**		(II) International Standard number	(III) Requirements in International Standard		(IV) Classification and details of technical deviation between **JIS** and the International Standard by clause Location of deviation: text Indication method: dotted underlines		(V) Justification for the technical deviation and future measures
Clause	Content		Clause	Content	Classification by clause	Detail of technical deviation	
8 Window thickness index			8	Almost identical with **JIS**.	MOD/ alteration MOD/ selection	Altered since the energy of ^{133}Ba is incorrect. ^{155}Eu is added as index, and it is made selectable.	The proposal of revision will be presented when **IEC** Standard is reviewed. Because it is generally a useful index.
9 Timing			9	Almost identical with **JIS**.	MOD/ selection	The test method by ^{60}Co is added, and it is made selectable.	Because it is generally a useful index.
9.1 Measurement system of timing resolution			9.1	Identical with **JIS**.	IDT	—	—
9.2 Determination of timing resolution			9.2	Identical with **JIS**.	IDT	—	—
10 Temperature cycle			10	Identical with **JIS**.	IDT	—	—
10.1 Temperature cyclable detector			10.1	Identical with **JIS**.	IDT	—	—
10.2 Annealable detector			10.2	Identical with **JIS**.	IDT	—	—
—	—		11	Low background germanium detectors	MOD/ deletion	Deleted since the content described in **IEC** Standard is common knowledge and does not give specifications.	No difference in technical content.

Overall degree of correspondence between **JIS** and International Standard: MOD

NOTES 1 Symbols in sub-columns of classification by clause in the above table indicate as follows:

— IDT: Identical in technical contents.

— MOD/deletion: Deletes the specification item(s) or content(s) of International Standard.

— MOD/addition: Adds the specification item(s) or content(s) which are not included in International Standard.

— MOD/alteration: Alters the specification content(s) which are included in International Standard.

— MOD/selection: Parallel requirement(s) for specification content(s).

2 Symbol in column of designated degree of correspondence between **JIS** and International Standard in the above table indicates as follows:

— MOD: Modifies International Standard.

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